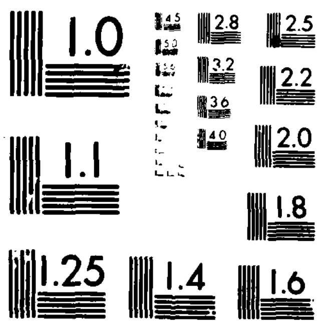
AD-A085 464 ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT--ETC F/G 20/4
TECHNICAL EVALUATION REPORT ON THE FLUID DYNAMICS PANEL SYMPOSI--ETC(U)
MAR 80 H H THOMAS
UNCLASSIFIED AGARD-AR-157 NL

1 OF 1
AD
A085464

END
DATE
FILMED
7-80
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AGARD-AR-157

AGARD-AR-157

AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

7 RUE ANCELLE 92200 NEUILLY SUR SEINE FRANCE

ADA085464

AGARD ADVISORY REPORT No. 157

Technical Evaluation Report on the Fluid Dynamics Panel Symposium on Aerodynamic Characteristics of Controls

NORTH ATLANTIC TREATY ORGANIZATION

DISTRIBUTION AND AVAILABILITY ON BACK COVER

(14) AGARD-AR-157

NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

(11) Mar 82

(12) 21

(9)

AGARD Advisory Report No.157

(6)

TECHNICAL EVALUATION REPORT

on the

FLUID DYNAMICS PANEL SYMPOSIUM

on

AERODYNAMIC CHARACTERISTICS OF CONTROLS

by

(10) H.H.B.M. Thomas
Aerodynamics Department
Royal Aircraft Establishment
Farnborough, Hampshire, England

By

Dist A

This Advisory Report was prepared at the request of the Fluid Dynamics Panel of AGARD.

400 043

THE MISSION OF AGARD

The mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

- Exchanging of scientific and technical information;
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving the co-operation among member nations in aerospace research and development;
- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field;
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community.

The highest authority within AGARD is the National Delegates Board consisting of officially appointed senior representatives from each member nation. The mission of AGARD is carried out through the Panels which are composed of experts appointed by the National Delegates, the Consultant and Exchange Programme and the Aerospace Applications Studies Programme. The results of AGARD work are reported to the member nations and the NATO Authorities through the AGARD series of publications of which this is one.

Participation in AGARD activities is by invitation only and is normally limited to citizens of the NATO nations.

The content of this publication has been reproduced
directly from material supplied by AGARD or the author.

Published March 1980

ISBN 92-835-1351-7

Printed by Technical Editing and Reproduction Ltd
Harford House, 7–9 Charlotte St, London, W1P 1HD

CONTENTS

A TECHNICAL EVALUATION REPORT FOR THE SYMPOSIUM ON "AERODYNAMIC CHARACTERISTICS OF CONTROLS" (NAPLES, ITALY, 14-17 MAY 1979)

by

H. H. B. M. Thomas

Aerodynamics Department,
Royal Aircraft Establishment,
Farnborough, Hampshire, England

1 INTRODUCTION

During the last decade there has been a progressive development of the extent to which aircraft control systems have been allowed to impact upon the basic airframe design. This process has certainly been evolutionary in nature, but in recent years the control system has been increasingly turned to as the means by which the designer may effect certain performance improvements with possible weight savings. However, the replacement of the mechanical control system by a wholly electrical system (the 'fly-by-wire' system) was a necessary and fundamental step that had to become a reality before the above design philosophy could be embraced wholeheartedly. The technology which underlies this design philosophy is commonly known as Active Control Technology (ACT) and the vehicles which result are sometimes termed Control Configured Vehicles (CCV).

There is a whole range of system functions which would be expected to react favourably on the efficiency of a design in this way. They include augmentation of the stability, relaxed stability, manoeuvre enhancement, manoeuvre load alleviation and limitation, decoupling of response, control of flutter modes, ride control, fatigue alleviation and even departure and spin prevention.

Whatever the consequences of adopting this approach to aircraft design on the importance of the aircraft's aerodynamic characteristics generally, it is evident that greater stress is placed on the need to understand the factors that determine the nature of the control (or motivator) forces. There is also a need to be able to predict these forces at an early stage in the design cycle and to explore more efficient means of generating control forces and moments. Recognition of this fact caused the Fluid Dynamics Panel of AGARD to arrange a symposium the stated aims of which were "to reveal the more important aerodynamic problems of controls with which we are faced, to establish current progress and to determine the lines along which research should prove most fruitful". The symposium entitled "Aerodynamic Characteristics of Controls" took place during 14-17 May 1979 at the Italian Air Force Academy, Pozzuoli, Naples, Italy. The participants numbered 139.

2 DISCUSSION

The four-day programme was subdivided into six sessions, which covered in turn the following topics: general aspects, novel controls, direct-force controls, dynamic effects and interference effects. Before an attempt is made to assess in an overall fashion the significance of the presentations and to draw conclusions therefrom, a brief account of the individual presentations is given. Insofar as possible this will seek to inter-relate these so that an overall picture may emerge.

2.1 General Aspects

In an introductory survey M. Poisson-Quinton outlined the different ways the implementation of active control technology would impact on the aerodynamic design and upon the task facing the aerodynamicist. This presentation undoubtedly enabled those not already involved in any aspect of active controls to get the symposium into perspective. Körner, in the second part of the same paper, reviewed the position as regards theoretical predictions of control characteristics throughout the speed range. He concluded that the calculation methods for subsonic, attached-flow conditions had already reached a satisfactory level of accuracy and that the general problems of three-dimensional flow, including drag estimation, lay within our grasp. The position in supersonic, attached flow was assessed to be in much the same state.

In contrast, the difficulties which beset prediction in transonic, attached flow conditions were stressed. Not least of the problems facing the theoretician here is the doubtful value of direct comparison with wind-tunnel results subject to appreciable, but unknown, scale and interference effects. The discussion also considered the prospects of treating flows with leading-edge vortices and more general forms of flow separation. Although some progress had been made, it was considered that theoretical prediction in these cases remains a long term aim. In spite of the fact that the first figure of the paper indicated lateral controls as among the topics to be discussed no specific mention was made to problems in this area.

The next paper (Jean Ross and Thomas) reviewed the data already available on the aerodynamics of controls. To put the survey into perspective the authors illustrated in a graphic way the evolution of the overall aircraft system from the simple unaugmented aeroplane to the "control configured vehicle" and the way in which this progression has

increased the relative importance of the motivator (control surface etc) characteristics. The difficulties of obtaining reliable estimates of these characteristics were emphasised especially when it is borne in mind the part that maximum control powers, mutual interference between airframe and motivator, between motivator and motivator and the general non-linearity of these characteristics at high angle of attack will play in the active control system. The greater emphasis placed on increased effectiveness was used to stress the gains that may accrue from engine-airframe integration.

By relating the present standard of knowledge to the relevance of the data to design the paper sought to highlight the areas needing increased attention. Finally it was concluded that wind-tunnel tests will remain an important and vital feature of the design procedure and that the tests themselves may be more exacting.

The account of the correlation of flight and wind-tunnel measured control effectiveness for the F15 aircraft presented by Agnew and Mello illustrated the use of an extensive wind-tunnel test programme in the development of an airframe and a control system. Direct and indirect aerodynamic forces and moments due to twin rudders, ailerons and stabilators (tail surfaces) were measured in the wind-tunnel and deduced from analysis of time histories of the actual aircraft's motion. With the notable exception of the pitching moment derivative with respect to tailplane deflection, the characteristics obtained from wind-tunnel and flight tests were in good agreement throughout the flight envelope, which in this case is extensive. Other quantities which differed were the pitching moment due to deflection of the inlet ramp of the aircraft's propulsion system and the zero-lift pitching moment coefficient. Reasons were advanced for these discrepancies. In the case of the tailplane effectiveness it was suggested that dynamic effects were the cause, whilst the others were attributed to the inability of the wind-tunnel tests to simulate adequately the high Reynolds-number flight conditions.

In the final paper of this session Woodward and Keating described the results of wind-tunnel tests aimed at examining the effect on the linearity of control effectiveness of varying gaps, vents and spoiler deflection for a spoiler of fixed overall geometry fitted to a typical flapped transport aircraft wing. The main conclusions drawn from these investigations were:

(i) Overall, the most effective type of spoiler tested was the moving shroud spoiler, with a forward hinge and formed from a portion of the trailing-edge of the flap shroud.

(ii) A gap beneath the leading-edge of the spoiler and venting through the flap shroud both improved the linearity of the spoiler characteristics.

Other test results described related to lift enhancement and roll control on a wing typical of a combat aircraft. It was found that chordwise-contoured flaps, that is, flaps produced by smooth, unbroken deformation of the aerofoil profile, produced the same lift as hinged flaps but at less drag. Asymmetric deflections of the flaps about a large mean flap angle was found to be only half as effective as at low flap angles. This reduced effectiveness was accompanied by increased yawing moments.

2.2 Novel Controls

Two sessions were devoted to this topic. In a lucid, compact and well-argued paper Kehrer discussed the impact of aircraft configuration on the use of the relaxed stability concept. The generalized common design features were a high thrust-loading, twin engines, high wing sweep, high wing loading, wing variable camber and twist with active controls. To establish the acceptable level of instability that can be tolerated it is necessary to examine the ability of the longitudinal control to recover the aircraft from a high angle-of-attack condition. It was concluded that, of the three configurations examined, aft-tailed, canard (of same proportions used for trim and manoeuvring) and tailless, the aft-tail arrangement can incorporate certain characteristics which favour its use for exploitation of the concept of relaxed stability. These findings are not necessarily universally true but the remarks about the differing flow fields in which the canard and aft-tail controls operate at high angles of attack must have general significance. As the author pointed out the findings can be interpreted as showing that "additional research is recommended to overcome these deficiencies". In addition this presentation drew attention to the need to improve the performance of the roll control at high angles of attack and cited examples of devices which show some promise.

In the second paper of this session the authors, Welte and Ehekircher, described the results of force measurements made on a 1/20 scale wind-tunnel model of a 35° swept-wing fighter configuration (with first an idealized fuselage and then a more realistic shape, not detailed).

Control surfaces deflected as longitudinal motivators in these tests included: aft-tailplane, leading and trailing-edge flaps, strake, a strake leading-edge flap and a strake vane (an additional small strake fitted to the nose region of the main strake). These in combination can be used to enhance lift and minimize trimmed drag.

The lateral controls investigated were conventional ailerons and all-moving wing-tip controls (of two different planforms). The latter proved a very effective roll-yaw control up to very high angles of attack.

Use of the strake leading-edge flap and an inboard trailing-edge flap on the wings as side-force producers was discussed in this presentation.

Devices to control the rolling and yawing moments in side-slipping conditions at high angle of attack were also investigated. These included differential deflection of wing leading-edge flaps and the fitting of so-called 'vortex fins' to the wing. It was not clear how the authors envisaged these flaps being used, but their effects were such as to suggest a complex scheduling of the angles of attack and side-slip within the control law. The 'vortex fins' seemed the more straightforward of the two.

This presentation contained much useful data and on that account it is regrettable that the Reynolds number of the low speed tests should be only 0.59×10^6.

The case for roll control using digitally controlled segmented spoilers was argued in the next presentation by Jonas, Wünnenberg and Hortsmann. Here the aim was to overcome the problems posed by the non-linear characteristics and tendency to reversal at low deflections often exhibited by one-piece spoilers. Like paper 4 the wind-tunnel tests used to acquire basic design data showed that the moving-shroud type of spoiler is the most effective in conjunction with high lift flaps. The paper exposed the problem of loss of control effectiveness at angles of attack beyond that for maximum lift without any discussion of the problems posed thereby. It is hoped to test a segmented spoiler arrangement in flight.

In the next paper of this session Lee (of Boeing Aerospace Co) described the design philosophy behind the use of flaps with upper-surface blowing in an active control manner on the YC14 aircraft.

Relatively small flaps, the hinge moments of which were of manageable proportions, were shown to produce large lift increments by efficient engine exhaust turning and supercirculation around the wing. During STOL landing approach the YC14 aircraft operates on the 'back-side' of the speed-thrust curve, that is, increased thrust is required for stabilized flight as airspeed is decreased. To bring out the advantage of active control system devised for the aircraft Lee discussed the consequences for the YC14, if its blown flaps were set at 60°. Curves of the response of the aircraft to a stick force input and a thrust increase were shown. These illustrated the results to be expected under these operational conditions, namely, that control force has more effect on airspeed that on flight path angle while the reverse is true of thrust change. As a result the pilot of such an aircraft would be forced to use unconventional back-side control techniques. If, however, the thrust and the flap deflection are changed together according to schedules, which can be determined from wind-tunnel data, pure accelerations along or normal to the flight path can be generated.

By use of the blown flap in this active-control fashion the designers of the YC14 had devised a flight system in which stick force yielded a change in the flight path angle with only very slight speed changes and the airspeed demand produced the required speed change with practically no change in the flight path.

In the next presentation based on the paper by Moynes and Wallace Nelson Jr, the development of active control systems based on the use of segmented trailing-edge flaps (flaperons) was traced from the acquisition of the necessary aerodynamic data through to the design of the control systems. This presentation provided a perfect illustration of some of the general points raised earlier in paper 2. Of interference effects it was remarked that flaperons had significant effects on the flow-field over the tail and fins. It was stated that "these downwash and sidewash effects determine the most effective flaperon design and in addition contribute to the complexity of the aerodynamics". On this later point Ross and Thomas had earlier noted that wind-tunnel tests may become more exacting for this type of project. This view was reinforced here by the remark that the configuration is "one that is capable of bringing a grimace to the face of those responsible for test requirements and data reduction". The importance of aeroelastic effects in the context of roll control was stressed.

The advantage of the segmented flaperons was shown to lie in the fact that deflection of the inboard portions in opposition to the outer panels not only had a favourable rolling moment interference on the empennage, but permitted the level of the induced yawing moment to be adjusted. The improvements were sufficient to remove reversal of roll control at a Mach number of 0.95 with no hint of reversal at Mach number 1.1.

The way the different aerodynamic controls could be used actively in the areas of longitudinal control, ride smoothing, direct lift, aircraft pointing in pitch, vertical flight path control and manoeuvre enhancement was described.

Like the previous paper this presentation was a significant contribution in that it enabled participants at the symposium to appreciate in a tangible way the potentials of ACT.

The second session on Novel Controls opened with a review of AFFDL flight experience in the field of active control systems. In this review the authors, Johannes and Whitmoyer, managed to compress in a praiseworthy manner the experience of nine separate research programmes into a comparatively short paper. The first of the programmes described was the Load Alleviation and Mode Stabilization (LAMS) programme, principally concerned with the reduction of fatigue damage due to turbulence. It, nevertheless, did indicate potential benefits from decoupling of flight motions. Additional control

surfaces were incorporated into the B52 aircraft for the so-called CCV B-52 programme so as to enable the following control system concepts to be included: flutter mode control, manoeuvre load control, ride control, augmented stability and fatigue reduction.

At the same time attention was directed to the practicability of fly-by-wire systems with no mechanical back-up. Improvements were sought and achieved in the design of the flight control system of the modified F4 aeroplane. One lesson learnt from this programme was the desirability of arranging the aircraft's responses to be task-tailored for each phase of a mission through a "multi-mode control system". To put these concepts into effect needed the emergence of digital control systems.

The next major development was the PACT/CCV (Precision Aircraft Control Technology) programme using a redesigned F4 incorporating close-coupled canard surfaces. These rendered the unaugmented aircraft unstable and a relaxed stability system featured in these tests. To minimise the drag the canard surfaces were scheduled as a function of tail deflection. A direct lift capability was achieved not so much through the direct lift generated by deflection of the canards, which was offset by downwash losses on the wing (*cf* paper 2), but by the lift produced by the tailplane deflection needed to trim the pitching moment due to the canards. In the course of the wind-tunnel testing it was discovered that differentially deflected canards were efficient sideforce generators.

Direct sideforce control was explored using the variable stability, NT-33A aircraft, the sideforce in this case being produced by rudder deflection whilst the yawing moment produced in the process was cancelled by deflection of petal surfaces on wing-tip stores. The amount of sideforce available was limited. A higher level of sideforce was produced in a later programme using the YF16 aircraft by means of twin vertical canards. As already mentioned differential deflection of horizontal canards is an efficient means of producing sideforce, but on this particular configuration it was found that the directional stability was strongly dependent upon canard deflection at high angles of attack. Although pilots identified many beneficial applications for the unconventional aircraft motions that result from force control it was stated that "the question of how the pilot can best command direct force control modes has yet to be resolved. Separate, additional controllers for direct force control can increase the work load, cause cross-coupling and other compatibility problems".

An important general point made by the authors on the basis of their experience with the CCV YF16 was that "the aerodynamic interference and non-linearities noted during the CCV YF16 programme reinforced the importance of a thorough and accurate definition of the bare airframe aerodynamics". The need to tailor the characteristics of each control mode to the task in hand was again noted. Another programme, Digital Multimode Flight Control System on the AD-7D aircraft addressed itself to this question and showed that digital flight control systems can provide effective task-oriented control laws.

The Integrated Flight and Fire Control Programme had as its design aim the accurate delivery of air-to-ground weapons during evasive manoeuvring and pilot aided air-to-air tracking.

All the above mentioned functions are to be incorporated into a YF16 test aircraft designated AFTI-16 aircraft which relates to the Advanced Fighter Technology Integration Programme. As it has not proved possible to completely redesign the demonstrator aircraft the flexibility and growth of the control systems must come from software development alone. Overall this review of test programmes must have been very helpful to those in the audience not acquainted with the various prospects ACT offers.

From this general review Nguyen, Gilbert and Sue Grafton turned their attention to the particular problems of recovery from high angle-of-attack conditions which could face designs utilizing the concept of the relaxed stability system. The gist of the argument presented was as follows. It is inherent in such a design that, to a greater or lesser degree, the pitching moment is positive over a range in the angle of attack. If the nose-down pitching moment that can be generated by the pitch control is unable, or barely able, to overcome the nose-up moment, departure in angle of attack towards the deep stall trim point will ensue. In six degree-of-freedom manoeuvres two dynamic effects can adversely affect the recovery capability, these are the growth in angle of attack due to (1) kinematic effects of rolling and (2) the nose-up pitching moment due to inertia coupling.

The presentation went on to study the behaviour of two aircraft configurations, (A), a tail-aft design and (B), a close-coupled canard design. Configuration (A) had a moderately swept wing fitted with a highly-swept strake and an all-moving tail. Configuration (B) had a wing of somewhat higher sweep and three forms of pitch control were considered. These were elevons, canard flaps and all-moving canards. In the linear range the static margins of the two aircraft were respectively -0.04 and -0.20. The wing-body strake on configuration (A) caused a pitch-up in the angle of attack range, 40° to 50°. The tail effectiveness in producing nose-down pitching moment followed the expected trends, but it should be remarked that the degree to which it loses effectiveness as the angle of attack is increased depends on tail location (*cf* Kehrer[5]).

Departure of configuration (A) was studied in simulations of a rolling manoeuvre during an accelerated turn and the results presented showed that large excursions in angle of attack occurred. The discussion also demonstrated that it was possible to contain the departure by a suitable system design without unduly affecting manoeuvrability.

The pitching moment characteristics of the configuration (B), with neutral canard deflection, was shown to be increasingly nose-up to an angle of attack just greater than 20° followed by a more or less constant pitching moment with a final linear decrease beyond 55°. With these pitching moments it was shown that of the various pitch motivators tested on this configuration the all-moving canard was the most effective. Thus it would seem that this investigation favours the canard layout in contrast to Kehrer's findings. However, it must be pointed out that the investigation does not include a direct comparison of canard and tail-aft control for the same wing-body configuration.

The final paper in the second session of novel controls was that presented by Walker on the subject of fin design and ACT in the context of wings fitted with strakes. The strakes used in these tests were such as to generate two vortices independent of the wing and therefore passing close to the centrally mounted fin. From the results of kinetic pressures in the neighbourhood of the fin it was concluded that a high fin was desirable to avoid the worst of the losses in kinetic pressures in the wing wake. This result is probably generally true.

It was also concluded that rudder rather than all-moving fin was the preferred solution. Two things account for this finding (a) the deflection of the all-moving fin was limited to half that of rudder for structural reasons and (b) the wind-tunnel test showed an unexpectedly high level of rudder effectiveness (0.6 of that of the all-moving fin) in spite of its rather small chord-ratio. It was assessed that an active control system to ensure stability at high angles of attack could result in a 20 per cent decrease in the fin size.

2.3 Direct Force Controls

At this stage the symposium was to have passed on to consideration of direct force controls, but due to unforeseen circumstances Scolatti was unable to present his paper on this topic. Instead he illustrated the impact of control integration on aerodynamics by using as an example the IFFC programme, already referred to in paper 10.

He listed as the criticisms made against the delivery of unguided bombs on targets in a high threat environment the following:

(a) Takes too much time to achieve solutions.

(b) Long exposures increases vulnerability to unacceptable levels.

(c) The accuracy after a short-time solution is too low.

(d) The missions can only be successfully accomplished by a small fraction of the attacking force because of the high skill levels required in this high workload condition.

In the IFFC programme the aim is to improve accuracy and survivability by using a coupled flight and fire control system, whilst at the same time reducing pilot workload.

Such a development was seen as introducing a number of areas of aerodynamic data deficiencies. Besides the obvious ones that relate to the demands made by the high-g manoeuvres on knowledge of airframe aerodynamics, there was a need to improve our understanding of the aerodynamic characteristics of the weapons, before and after release, since this might involve unusual aircraft attitudes.

With the next paper of the fourth session attention was redirected to the problems of direct force controls. The presentation, based on the paper by Esch and Wünnenberg, described a programme of combined wind-tunnel and flight tests wherein direct sideforce and drag were produced by split flaps fitted to the wing pylons of the Alpha Jet aircraft. Wind-tunnel tests showed that the smaller chord flaps resulted in much smaller hinge moments for only a slight reduction in sideforce effectiveness. Interference effects between flap, store and airframe were large, so the total sideforce generated by pylon flaps on both port and starboard wings can be expected to be very configuration dependent. This feature is further emphasised by the manner in which downward deflection of wing trailing-edge flaps affected the sideforce produced. Beyond a deflection of 10° both pylon flaps on the port side (deflected to starboard) lost effectiveness as the deflection of the trailing-edge flap was increased. Some compensation occurred on the inboard pylon flap of the starboard wing, whilst the outboard flap on this wing produced a nearly constant sideforce. Angle of attack has a considerable influence on the sideforce produced and the trends with increase in angle of attack were similar to those with trailing-edge flap deflection, except that the degree of compensation on the inboard starboard pylon flap was much less.

The pylon flaps proved effective drag producers and tests over the Mach number range 0.2 to 0.85 showed little dependence on Mach number. It was stated that the intention now was to proceed in 1980 to flight testing of a simple control system based on the pylon flap geometry favoured by the wind-tunnel test data.

Asymmetric vortex flows around the long, pointed noses of both aeroplanes and missiles and the associated sideforce and yawing moments have plagued designers for some time. It was therefore good to have a presentation which sought to convey some fundamental understanding of the flow phenomena involved and describe means of adjusting the flow characteristics and thereby control the forces. Such was the presentation based on the paper by Peake and Owen.

Since it is typical of the nose portions of aeroplanes and missiles a cone of 10° apex angle, the pointed nose of which was slightly rounded, was used in the tests. These included comprehensive measurements of pressure distribution around a cross-section at 0.87 of the cone length, of the velocity field by means of a laser velocimeter and flow visualization pictures using a vapour-screen technique. To permit jets to be introduced into the flow at a station 0.12 cone length aft of the nose, the nose portion of the cone was made hollow and detachable. Holes of two sizes (2.4 mm and 3.6 mm diameter) were introduced at different positions around the cross-section at this station.

At angles of attack which yield a symmetrical flow pattern the authors detected a pair of small secondary vortices tucked beneath the primary pair. It seems that increased angle of attack brings in its train agitation and unsteadiness of these vortices. This disturbance seems to impose motion on the primary vortices so that they take up the asymmetric arrangement. The way various blowing arrangements affected the flow and its associated force was described. Air was blown tangential (forward and backward) to the surface as well as normal to the surface. There was no noticeable difference between the effects of the first two but both were inferior to the normal blowing arrangement. To have the maximum effect on the asymmetry the investigators found that it was necessary to introduce the single jet under the vortex that is further from the body surface. The circumferential location is also critical.

It was concluded by the authors of the paper that a properly located jet of quite low momentum was sufficient "to reduce the sideforce to zero and to subsequently reverse the direction of the sideforce". Interesting and illuminating though the findings of the investigation described are,it is by no means clear that the most effective means of utilizing the knowledge gained has been exposed. There were also some disquieting features in the test results, for example, the affect of changing jet momentum at a given (relative) angle of attack was examined, but it is difficult to reconcile some of the results quoted with those given for the fixed momentum tests. Again evidence was given that the 'no blow' condition was identical with the basic nose for a given nose frustrum. However, it was found that the results for the 'no blow' case for the different, but supposedly identical geometry, frustrums differed in a non-systematic manner. This is illustrated in Fig 1, which is thus an eloquent comment on the complexity of the problem.

Rix and Hanke in their paper [16], which was the subject of the next presentation, were mainly concerned with the mathematical modelling of a direct lift control system employing a combination of a trailing-edge flap and a spoiler. Wind-tunnel measurements were made of the characteristics of the spoiler and the flap, independently and in combination. On the basis of these data a system was designed for installation in the HFB 320 aircraft. Motion histories in response to various control inputs were obtained, from which were identified the different stability and control parameters. A point of interest in this context is that the control inputs were commanded by a program running on the onboard digital computer.

The main conclusions of this investigation were:

(i) A pre-requisite for accurate identification of the control parameters is the identification of the stability parameters using an optimized input to excite adequately all the modes of the aircraft.

(ii) Control behaviour could be described by a linear model, although relatively high amplitude and surface rates were used.

(iii) Lift lag effect seems so low as to be negligible.

(iv) Wind-tunnel and flight determined characteristics of the spoiler control differ appreciably, although the same trend with flap deflection occurs.

In the next presentation, the concluding one on the topic of direct force control, Sonnleitner described the results of a series of wind-tunnel tests of a generalized fighter aircraft model fitted with a variety of surfaces intended to contribute to control and/or stability. Tests were made of aft surfaces mounted in both the dorsal and ventral position. The results are in line with other data sources. Of interest are the results of tests on single centrally mounted canards and twin surfaces mounted at the same longitudinal station. The influence of position and number of surfaces on the main lateral stability and control characteristics, as well as on the pitching moment, were described. Highly non-linear variation with angle of attack seemed a common feature of the results at high angle of attack. Below the stall the direct lateral effects ($Cy\delta_c$ and $Cn\delta_c$) drop off roughly linearly with the angle of attack.

2.4 Dynamic Effects

The fifth session of the symposium was devoted to dynamic effects under which general title were included four presentations relating to unsteady or oscillatory aerodynamics and two to the essentially quasi-steady aircraft dynamics. It opened with a presentation by Destuynder[18], who reviewed the problems in the unsteady flow field posed by the use of active control systems.

It was concluded that theory offered a reasonable basis for estimation in the subcritical flow regime, but that transonic theory, even allowing for recent progress in attempting to account for aerofoil thickness, boundary layer and shock effects, still left a great deal to be desired (*cf* paper 1).

Application of surfaces to the problem of gust alleviation and flutter control were considered.

In that part of the paper concerned with the aerodynamics of spoilers it was noted that deflection of an adjacent flap had a powerful effect on the spoiler forces (*cf* papers 4, 16). Here was also noted one of the more important (if unexpected) effects, namely, the substantial loss in spoiler effectiveness as the frequency parameter was increased. It was concluded that much more intensive testing of spoilers was called for before their widespread use could be adopted.

This presentation was followed by another on unsteady flows, but this time restricted to two-dimensional flow. It was based on the paper[19] by Grenon, Desopper and Sides and in it were described the results of tests on a 16 per cent thick supercritical aerofoil fitted with a 25 per cent chord trailing-edge flap, under steady and oscillatory conditions. These results were compared with theoretical results based on various methods and the comparisons indicate the degree of progress made in recent years in the calculation of steady and unsteady flows (*cf* paper 1, 18).

From the problems of two-dimensional flap controls the next presentation, based on the paper[20] by Mabey, McOwat and Welsh, turned the attention of the symposium participants to a comparison of measured and calculated oscillatory pressure distributions on a swept-back half wing fitted with a part-span trailing-edge flap. A primary objective of the investigation was to obtain direct evidence of the importance of boundary layer thickness and determine appropriate test conditions at different speeds. On the 9 per cent thick symmetrical wing employed in these tests the boundary layer had a large effect on the pressures generated by the oscillating flap. The thinner boundary layers at the hinge line produced by free transition were more representative of the full-scale conditions at subsonic speeds and resulted in higher forces than the fixed transition tests. An accompanying increase in phase lag was not expected and is, as yet, unexplained. At transonic speeds it is necessary, according to the authors, to ensure a turbulent shockwave/boundary-layer interaction, whilst the boundary layer itself should be as thin as possible. This implies either fixing transition just upstream of the shock or increasing the Reynolds number to the point at which a turbulent shockwave/boundary-layer interaction is obtained with free transition.

Once again the shortcomings of the theoretical methods particularly at transonic speeds were noted.

Many wind-tunnel tests and aircraft systems have featured spoilers, yet the mechanism of the flow change produced by deflection of a spoiler is only imperfectly understood. A presentation which described an investigation which sought some fundamental understanding of the flow around a spoiler was most welcome. This, the last on unsteady flows, was based on the paper by Siddalingappa and Hancock[21].

In the first place steady flows about a spoiler mounted on the floor of a tunnel were examined by flow visualization and pressure distribution measurements. Ramp change in spoiler angle were next investigated and it was found that when changing the spoiler angle from 0 to 35° in about 0.0125 seconds, about four times this time was needed for the flow to become established. On the contrary in going from 35° to 0° the flow virtually follows the spoiler motion in a quasi-steady manner. When these types of experiments were repeated with a spoiler mounted aft on an aerofoil section with ramp changes of deflection between 0 and 45°, in both directions, in a time of 0.032 seconds, the pressures took about four times the operating time to establish themselves for increasing deflection and somewhat less for decreasing deflection. However, when rates of application which are more representative of those to be used in an active control system (45° in 0.15 seconds) were applied the pressure response in the region behind the spoiler became virtually quasi-steady. This is in line with the findings of paper 16.

In addition some pressure measurements were taken with the spoiler mounted on the tunnel floor oscillating through the range 0 to 35° at 1 Hz and 5 Hz. Little difference was noted in the results (*cf* paper 18).

The next presentation, based on the paper[23] by Danesi, Smolka and Borrini, demonstrated the improvements that could be effected by incorporating an active control system into an existing design (Boeing 747). An account was given of a study in which the existing control devices (or motivators) had been used to reduce manoeuvre load, attenuate gust response and load and reduce drag. It was found that by use of the wing control surfaces alone a reduction of 6 per cent in the wing root bending moment could be achieved. A finding of particular interest is that the activity levels of the motivators were found to be compatible with the assumption of linearity. Since the wing mounted controls supplemented the elevator pitching moment an attempt was made to turn this to advantage by decreasing tail size. This proved counterproductive in as much as it was shown that the flying qualities worsened.

From this study of an active control system of a transport aircraft attention was directed to use of blowing as a means of controlling fore-body vortices and the out-of-balance forces these create. The presentation was based on the paper[24] by Skow, Moore and Lorincz. In the course of this it was explained how by means of a series of water and wind-tunnel tests it had been demonstrated that tangential blowing in an asymmetric fashion could ensure the generation of yawing moment increments comparable to those of the rudder at low angle of attack, thus providing an efficient alternative to the rudder at high angles of attack. Six degree-of-freedom calculations demonstrated the efficiency of

the device in recoveries from departure and spin conditions. Its alternative use in a departure/spin inhibitor system was briefly discussed.

2.5 Interference Effects

The symposium now entered its sixth and last session for which the topic being discussed was interference effects on aeroplanes and missiles.

The opening presentation, based on the paper[25] by Smith and Nielsen, was concerned with the non-linear interference effects present when cruciform, all-moving canard surfaces are used to control a missile. Many sources of interference were identified and semi-empirical methods of accounting for some of them were displayed. The influence of fin position through its local 'roll' angle (or what is equivalent, sideslip) and the cross-coupling of pitch and yaw control remain matters that require further investigation. It was concluded that a purely theoretical approach to the problem of predicting the aerodynamic characteristics of missile configurations at high angle of attack remains a remote prospect. A plea was made for a series of systematic tests to provide a data base to enable methods such as those outlined to be developed.

In contrast the next presentation, based on paper 26, by Gersten and Gluck, showed how far the problem of interference between a lifting surface and the wake of another lifting surface could be tackled by use of relatively simple theoretical concepts. It was shown that the two well-known effects of reduction in stream velocity (or kinetic pressure) and the change in stream direction (downwash) failed to account fully for the interference. A third effect, that of the non-homogeneous velocity distribution in the stream impinging on the second aerofoil was examined theoretically and experimentally in two-dimensional flow. It was found to result in significant incremental forces. Applied to the estimation of the pitching moment of a wing-tail combination over an extended range in the angle of attack,estimates including this third effect were shown to yield results in good agreement with experiment.

A systematic series of wind-tunnel tests of closely coupled canard-wing combinations formed the subject of a presentation, based on the paper[27] by Brocard and Schmitt. In these half-model tests canards of two leading-edge sweeps, a range of aspect ratio and location (up and down as well as fore and aft) are to be tested.

The influence of the canard on the development of the vortex flow around the wing was illustrated by the results of water tunnel tests. It was shown that predictions of lift using the Polhamus leading-edge suction analogy for the contribution of the vortices were in reasonable agreement with the experimental results. The full range of measurements, when available, will form a useful addition to the data bank as well as valuable test cases for methods of calculation.

Gaps between an aerofoil surface and a flap control have a detrimental effect on the effectiveness of the flap and although semi-empirical means of accounting for these losses have been devised, the flow mechanisms involved have not been closely studied. The presentation, based on the paper[28] by Michael and Hancock, described a combined experimental and theoretical investigation designed to redress the balance. The experimental results displayed covered overall forces, pressure distributions and boundary layer measurements and consideration was given to how the effects noted could be incorporated within the advanced numerical methods of predicting aerofoil and wing characteristics. The direct application of the AMO Smith method is ruled out because of the relative size of practical control gaps.

Two approaches to the problem were discussed. In the first an attempt would be made to model the gap by means of an upper surface source and lower surface sink, the strength of these being fixed by the upper surface outer inviscid flow and the need to preserve mass flow within the gap. The second method would consist of modification of the profile to account for the displacement effect of the source and sink in the neighbourhood of the gap.

In the next presentation, based on the paper[29] by Perinelle and Mifsud, a return was made to the complex aerodynamics of missiles. Canard and tail-aft arrangements were discussed, but only single plane interference problems were examined. The main features studied were maximum lift and hinge moment. In connection with the latter topic an extremely interesting idea was discussed. This consisted of using a double trapezoidal surface to minimise the shift in the centre of pressure with Mach number, in going from subsonic to supersonic speeds. The presentation demonstrated that the concept could be successfully exploited.

The last presentation of the symposium, based on the paper[30] by Neppert and Sanderson, described the results of various wind-tunnel tests of models of the Hansa Jet and the Airbus A300 aircraft. In the first series of tests described the aim had been to improve elevator effectiveness. The use of slotted elevators, lower-surface vortex generators forward of the elevator and sealing of the end gaps on the control were examined. Significant gains were shown to result from the first two modifications for up-going elevators. Other topics considered were the interference between split rudder controls and the effect of flap sweep on the contribution of the flap deflection to rolling and yawing moments due to sideslip. By arranging for the flap to unsweep as it is deflected the flap increment to the derivatives of rolling and yawing moments with respect to sideslip is much reduced. The arrangement seems practicable and of considerable interest, as the results displayed showed that the above benefits could be achieved with no loss of the maximum lift.

3 CONCLUSIONS

In an attempt to assess the overall significance of the presentations with respect to the furtherance of knowledge and in the forward planning of research and development programmes the following conclusions are offered.

(1) Whilst admittedly steady progress has been made in methods of calculating aerodynamic characteristics[1,2,18,19] over the last few years, much remains to be achieved. More remains to be done even for the solution of the inviscid flow problem at transonic speeds. As for separated flows only in those with well-ordered flow structures (such as highly-swept wings with leading-edge vortex flow) is any progress discernible. No attempt seems to have been made to treat the three-dimensional problem in the case of more general forms of separated flow.

A reliable means of accounting for viscous effects in the more amenable flow regimes of subsonic and supersonic is urgently needed.

(2) As regards the characteristics of controls in oscillatory flows the same sort of steady progress emerges, but here too the transonic flow problem emerges as that needing the most urgent and intensive attention (see 1, 18, 19, 20 and 21).

(3) Aerodynamic interference and cross-coupling effects are now recognised as being increasingly important especially in the context of active control systems[2,6,7,9,12,16,25,26,27,29,30].

Although it is possible by suitable system design to sometimes turn these effects to advantage[9], it is necessary to have *ab initio* knowledge of the nature and extent of the interference. At present, these effects are not well understood.

(4) Some applications of spoiler controls within an active control system necessitate knowledge of their dynamic, rather than their quasi-steady, characteristics. The evidence presented of these being subject to a strong influence of the frequency parameter stresses the need for much more extensive testing, particularly of practical three-dimensional arrangements.

Similar needs exist in respect of oscillating flap-type controls.

(5) Disturbing discrepancies keep turning up in comparisons of data from wind-tunnel and flight tests. At high speed it is necessary to account adequately for aeroelastic effects, but in many instances the discrepancies are not readily explicable, much less quantified.

Data from *ad hoc* tests do not lend themselves readily to correlation, because the opportunity seldom exists to investigate in depth possible causes of the discrepancies. There is a case for planning some specialised systematic work in this area.

(6) Linked to the previous conclusion is that of the need for an improved data base to aid the development of theoretical and semi-empirical methods of estimation. However the symposium has shown the extent to which aircraft design, at present, depends on development by wind-tunnel testing thereby creating another call for time in these facilities[2,7,8,9].

(7) The greater role that controls will play in aircraft design through the expanding use of active control systems results in an increased need to study their aerodynamic characteristics, but, at the same time, there will still be a need to know the other aerodynamic characteristics of the aircraft to a reasonably high level of accuracy. This point was made several times during the symposium as the following quotations show.

In a speculative attempt to assess the relative importance of different motivator characteristics within the different active control systems, Ref 2 stresses that all "these characteristics are of importance". Later in the same paper in relation to coupling of motivators within an active control system it states that "such concepts need an extensive aerodynamic data base so that the best choice of motivators can be made". Whilst in the concluding remarks to the same paper it is suggested that "in future, the more intensive use of active controls could imply a need for aerodynamic improvement". Again the authors of Ref 9 in a discussion of an active control system using segmented flaperons decide that it seems that "the ability to predict what the value of an aerodynamic coefficient is, is more important that the actual value of the coefficient". These views are reinforced by a statement in the conclusions of the review of the extensive AFFDL experience in the ACT field. This asserts that "the advent of ACT design techniques, rather than reducing the importance of bare airframe aerodynamics, has resulted in an increased requirement for a thorough and accurate definition of aerodynamic characteristics".

(8) The possible impact that direct force control, in both the longitudinal and lateral planes, can have on a combat aircraft's survivability and combat effectiveness did not receive the attention it deserves at this symposium. It is possible that discussion at the symposium was handicapped by the lack of the paper Dr Scolatti was to have presented on the topic of direct force control.

(9) The appearance on long pointed fore-bodies at high angles of attack of forces out of the plane of flow has long been a matter of concern to designers of aeroplanes and missiles alike. Detailed flow investigation on a basic shape of fore-body[15] and tests on

a specific aeroplane body[24] indicate that blowing has an important part to play in exercising control over these forces and moments.

Notwithstanding the significance of the work done so far there are indications that further investigations are needed. In addition more thought is required as to the best way to utilize this facility for interacting with the flow.

(10) In past discussions of ACT potentials some emphasis had been placed on the need to increase the effectiveness of the motivators. Yet in the present symposium no evidence seemed to be advanced to suggest that any of the schemes discussed were deficient in this respect.

(11) Some results were presented that showed the important part engine-airframe integration can play in providing additional control forces and moments or in augmenting those already generated by the external flow, but the topic received little attention till the 'round-table' discussion when a strong plea was made for intensification of effort on this aspect of control.

(12) Clearly more of the aerodynamics of canard configurations need further investigation in wind-tunnels, since for different wing configurations (possibly reflecting different mission requirements) the relative merits of canard and tail-aft configurations can seem to be reversed[5,11].

(13) The impact of mission requirements on design did not surface sufficiently at the symposium, for example, the session on direct force controls did not consider their relevance to specific requirements. Indeed the same is true of the entire manoeuvre capability designers are striving to incorporate in their aircraft.

Perhaps this is a matter not so much of the military strategist and tacticians giving specific guidance in the form, "we want this and that to such and such a degree", but rather a need for a continuing dialogue between these people and the aeronautical engineers. In short a symposium on the topic is perhaps indicated.

4 RECOMMENDATIONS

On the basis of the above conclusions and the 'round-table' discussion the following actions are recommended.

(1) Consideration should be given to the most fruitful means of contributing to a representative and comprehensive data base. This needs to take into account the view expressed in Ref 2 that, "it is unlikely that systematic testing of a complete series of models can be undertaken to fill the gaps in knowledge, as this seems prohibitive in time and money. More may be gained, perhaps, by restricting attention to a few particular basic layouts and exploring variations on these basic themes". This remark reflects the configuration-dependent nature of the aerodynamics of present-day aircraft as indicated in a number of the presentations. One particular area which urgently needs further wind-tunnel tests relates to the canard versus aft-tail debate.

(2) An important facet of the acquisition and analysis of experimental data is the correlation of wind-tunnel and flight test results. In the light of the evidence presented it becomes pertinent to question whether we should abandon in a partially unresolved state those comparisons recorded in the literature.

Accordingly consideration needs to be given to the action most likely to advance our knowledge and understanding. Do we seek a more critical reappraisal of some of the existing attempts at correlation or do we consider it is likely to prove more profitable to set up new specialised tests?

(3) Although in the short term theory can only play a limited part in the design process, it can and must assume much greater importance. To this end every encouragement must be given to work aimed at improving our ability to calculate aerodynamic characteristics.

In this context serious consideration should be also given to specially devised experiments that can help to advance theory.

(4) More studies are required to identify the importance of unsteady dynamic control characteristics in the context of the various active control systems.

Additional oscillatory wind-tunnel tests on the effect of frequency parameter on the characteristics of the different motivators are urgently needed for these studies.

(5) More light needs to be shed on the interaction between the aerodynamics of the airframe and the motivators and the active control system in its various roles. Undoubtedly the remarks made at the symposium will not be found wanting, but these do not answer the question of what characteristics are worth striving to attain.

(6) As engine-airframe integration was not considered in any depth at this symposium, it is recommended that the programme of the forthcoming symposium at Toulouse in the spring of 1981 should feature a number of papers on the control aspects.

(7) Since the development of active control systems embraces a number of disciplines, the need for inter-disciplinary symposia is recognised and it is recommended that the need should be catered for through the medium of joint symposia on this topic organised by the relevant Panels of AGARD.

REFERENCES

1. Ph Poisson-Quinton and H. Körner. Theoretical aerodynamic methods for active control devices - Part 1.

2. A.J. Ross and H.H.B.M. Thomas. A survey of experimental data on the aerodynamics of controls, in the light of future needs.

3. J.W. Agnew and J.F. Mello. Correlation of F-15 flight and wind tunnel test control effectiveness.

4. D.S. Woodward, R.F.A. Keating and C.S. Barnes. Some wind tunnel measurements of the effectiveness at low speeds of combined lift and roll controls.

5. W. Kehrer. Flight control and configuration design considerations for highly manoeuvrable aircraft.

6. D. Welte and S. Ehekircher. Wind tunnel measurements and analysis of some partly unusual control surfaces on two swept-wing fighter-type aircraft.

7. K. Jonas, H. Wünnenberg and K.H. Horstmann. Roll control by digitally controlled segment spoilers.

8. A.H. Lee. The YC-14 upper surface blown flap: a unique control surface.

9. J.F. Moynes and W.E. Nelson Jr. Flaperon control - the versatile surface for fighter aircraft.

10. R.P. Johannes and R.A. Whitmoyer. AFFDL experience in active control technology.

11. L.T. Nguyen, W.P. Gilbert and S.B. Grafton. Control considerations for CCV fighters at high angles of attack.

12. D.J. Walker. Fin design with ACT in the presence of strakes.

13. C. Scolatti. Control integration technology impact.

14. P. Esch and H. Wünnenberg. Direct side force and drag control with the aid of pylon split flaps.

15. D.J. Peake and F.K. Owen. Control of forebody three-dimensional flow separations.

16. O. Rix and D. Hanke. In-flight measured characteristics of combined flap-spoiler direct lift controls.

17. W. Sonnleitner. Wind tunnel investigation of controls for DFC on a fighter-type configuration at higher angles of attack.

18. R. Destuynder. Problemes d'aerodynamique instationnaire poses par l'utilisation des gouvernes dans le controle actif.

19. R. Grenon, A. Desopper and J. Sides. Effets instationnaires d'une gouverne en ecoulement bidimensionnel subsonique et transsonique.

20. D.G. Mabey, D.M. McOwat and B.L. Welsh. Aerodynamic characteristics of moving trailing-edge controls at subsonic and transonic speeds.

21. S.R. Siddalingappa and G.J. Hancock. Unsteady aerodynamics of two dimensional spoilers at low speeds.

*

23. A. Danesi, S. Smolka and F. Borrini. Trajectory behaviour of a control configured aircraft subject to random disturbances.

24. A.M. Skow, W.A. Moore and D.J. Lorincz. A novel control concept to enhance departure/spin recovery characteristics of fighter aircraft through control of the forebody vortex orientation.

25. C.A. Smith and J.N. Nielsen. Nonlinear aerodynamics of all-movable controls.

26. K. Gersten and D. Gluck. On the effect of wing wake on tail characteristics.

27. Y. Brocard and B. Schmitt. Interaction aérodynamique entre un canard proche et une voilure.

28. C. Michael and G.J. Hancock. On the effects of gaps on control surface characteristics.

* Note – Paper 22 was cancelled.

REFERENCES (concluded)

29. J. Perinelle and L. Mifsud. Etude aérodynamique des gouvernes de missile.

30. N. Neppert and R. Sanderson. Some investigations concerning the effects of gaps and vortex generators on elevator efficiency and of landing flap sweep on aerodynamic characteristics.

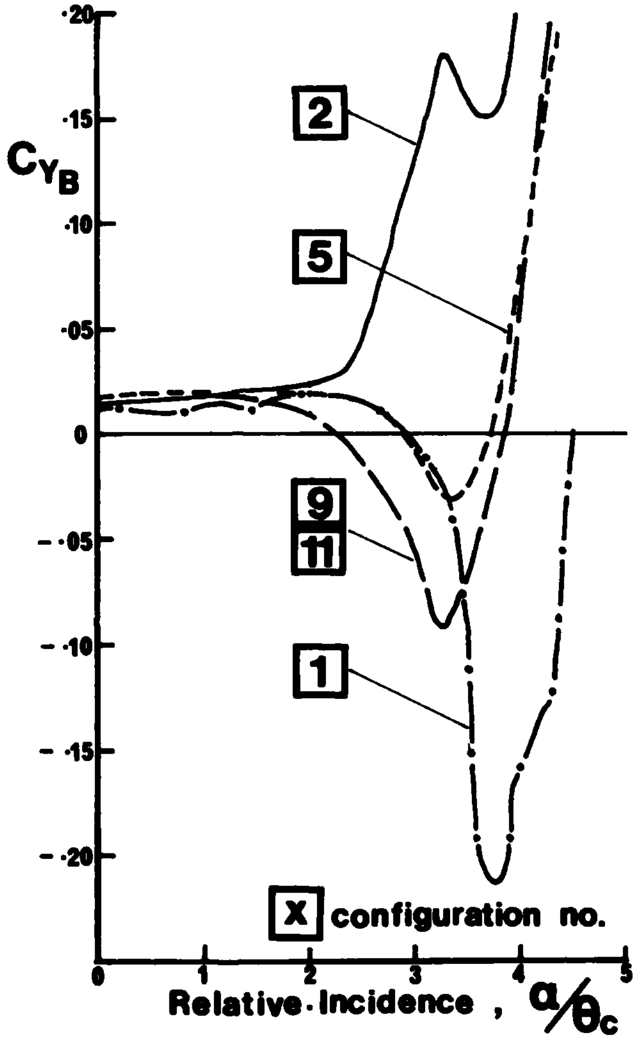


Fig.1. Sideforce coefficients for supposedly identical nose shapes, no blowing

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-AR-157	ISBN 92-835-1351-7	UNCLASSIFIED

5. Originator

Advisory Group for Aerospace Research and Development
North Atlantic Treaty Organization
7 rue Ancelle, 92200 Neuilly sur Seine, France

6. Title

TECHNICAL EVALUATION REPORT on the FLUID DYNAMICS PANEL SYMPOSIUM on AERODYNAMIC CHARACTERISTICS OF CONTROLS

7. Presented at

8. Author(s)/Editor(s)	9. Date
H.H.B.M.Thomas	March 1980

10. Author's/Editor's Address	11. Pages
Aerodynamics Department Royal Aircraft Establishment Farnborough, Hampshire, England	18

12. Distribution Statement

13. Keywords/Descriptors

Aerodynamic characteristics
Flight control
Control surfaces

14. Abstract

This report presents an evaluation of the papers presented and the discussion held during the AGARD Fluid Dynamics Panel Symposium on Aerodynamic Characteristics of Controls held 14–17 May 1979 in Pozzuoli, Italy. A brief discussion of the presentations and discussions is followed by a summary of conclusions and recommendations for action. The full test of the papers is available in AGARD Conference Proceedings No.262, published in September 1979.

AGARD Advisory Report No.157
Advisory Group for Aerospace Research and Development, NATO
TECHNICAL EVALUATION REPORT on the FLUID DYNAMICS PANEL SYMPOSIUM on AERODYNAMIC CHARACTERISTICS OF CONTROLS
H.H.B.M.Thomas
Published March 1980
18 pages

This report presents an evaluation of the papers presented and the discussion held during the AGARD Fluid Dynamics Panel Symposium on Aerodynamic Characteristics of Controls held 14–17 May 1979 in Pozzuoli, Italy. A brief discussion of the presentations and discussions is followed by a summary of conclusions

P.T.O.

AGARD-AR-157

Aerodynamic characteristics
Flight control
Control surfaces

AGARD Advisory Report No.157
Advisory Group for Aerospace Research and Development, NATO
TECHNICAL EVALUATION REPORT on the FLUID DYNAMICS PANEL SYMPOSIUM on AERODYNAMIC CHARACTERISTICS OF CONTROLS
H.H.B.M.Thomas
Published March 1980
18 pages

This report presents an evaluation of the papers presented and the discussion held during the AGARD Fluid Dynamics Panel Symposium on Aerodynamic Characteristics of Controls held 14–17 May 1979 in Pozzuoli, Italy. A brief discussion of the presentations and discussions is followed by a summary of conclusions

P.T.O.

AGARD-AR-157

Aerodynamic characteristics
Flight control
Control surfaces

AGARD Advisory Report No.157
Advisory Group for Aerospace Research and Development, NATO
TECHNICAL EVALUATION REPORT on the FLUID DYNAMICS PANEL SYMPOSIUM on AERODYNAMIC CHARACTERISTICS OF CONTROLS
H.H.B.M.Thomas
Published March 1980
18 pages

This report presents an evaluation of the papers presented and the discussion held during the AGARD Fluid Dynamics Panel Symposium on Aerodynamic Characteristics of Controls held 14–17 May 1979 in Pozzuoli, Italy. A brief discussion of the presentations and discussions is followed by a summary of conclusions

P.T.O.

AGARD-AR-157

Aerodynamic characteristics
Flight control
Control surfaces

AGARD Advisory Report No.157
Advisory Group for Aerospace Research and Development, NATO
TECHNICAL EVALUATION REPORT on the FLUID DYNAMICS PANEL SYMPOSIUM on AERODYNAMIC CHARACTERISTICS OF CONTROLS
H.H.B.M.Thomas
Published March 1980
18 pages

This report presents an evaluation of the papers presented and the discussion held during the AGARD Fluid Dynamics Panel Symposium on Aerodynamic Characteristics of Controls held 14–17 May 1979 in Pozzuoli, Italy. A brief discussion of the presentations and discussions is followed by a summary of conclusions

P.T.O.

AGARD-AR-157

Aerodynamic characteristics
Flight control
Control surfaces

and recommendations for action. The full text of the papers is available in AGARD Conference Proceedings No.262, published in September 1979.

This Advisory Report was prepared at the request of the Fluid Dynamics Panel of AGARD.

ISBN 92-835-1351-7

and recommendations for action. The full text of the papers is available in AGARD Conference Proceedings No.262, published in September 1979.

This Advisory Report was prepared at the request of the Fluid Dynamics Panel of AGARD.

ISBN 92-835-1351-7

and recommendations for action. The full text of the papers is available in AGARD Conference Proceedings No.262, published in September 1979.

This Advisory Report was prepared at the request of the Fluid Dynamics Panel of AGARD.

ISBN 92-835-1351-7

and recommendations for action. The full text of the papers is available in AGARD Conference Proceedings No.262, published in September 1979.

This Advisory Report was prepared at the request of the Fluid Dynamics Panel of AGARD.

ISBN 92-835-1351-7

FILMED

8